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(54) Abstract Title
Laser drilling of holes in materials

(57) The invention discloses methods and apparatus for laser drilling one or more holes in one or more materials using a laser radiation source emitting radiation having a wavelength or wavelengths, where at least some of the materials have been treated to change their absorption depths at the wavelength or wavelengths of the radiation. The material or materials may be treated by adding one or more dopants thereto. Or by irradiation, laser heating, material layering or lamination or combination thereof. The material or materials may comprise dielectric materials, and may be used in the construction of electrical interconnection packages such as printed circuit or wiring boards, ball grid arrays or multichip modules. The quality of the holes produced is superior to that produced when drilling undoped material with the same laser radiation source.

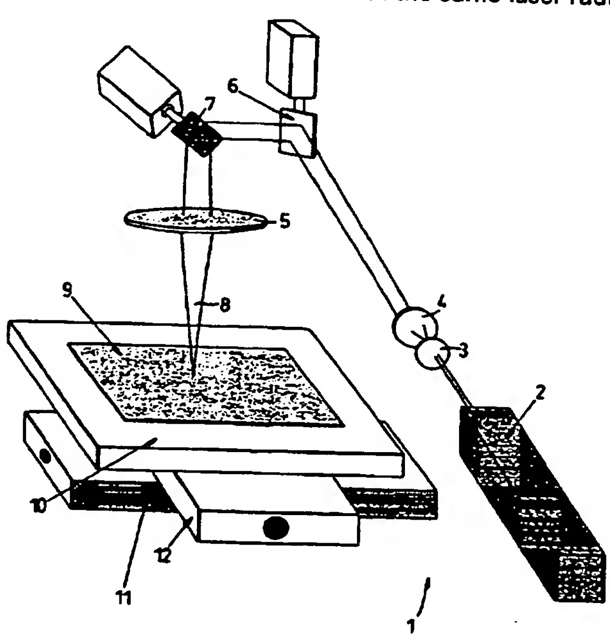

Fig. 1

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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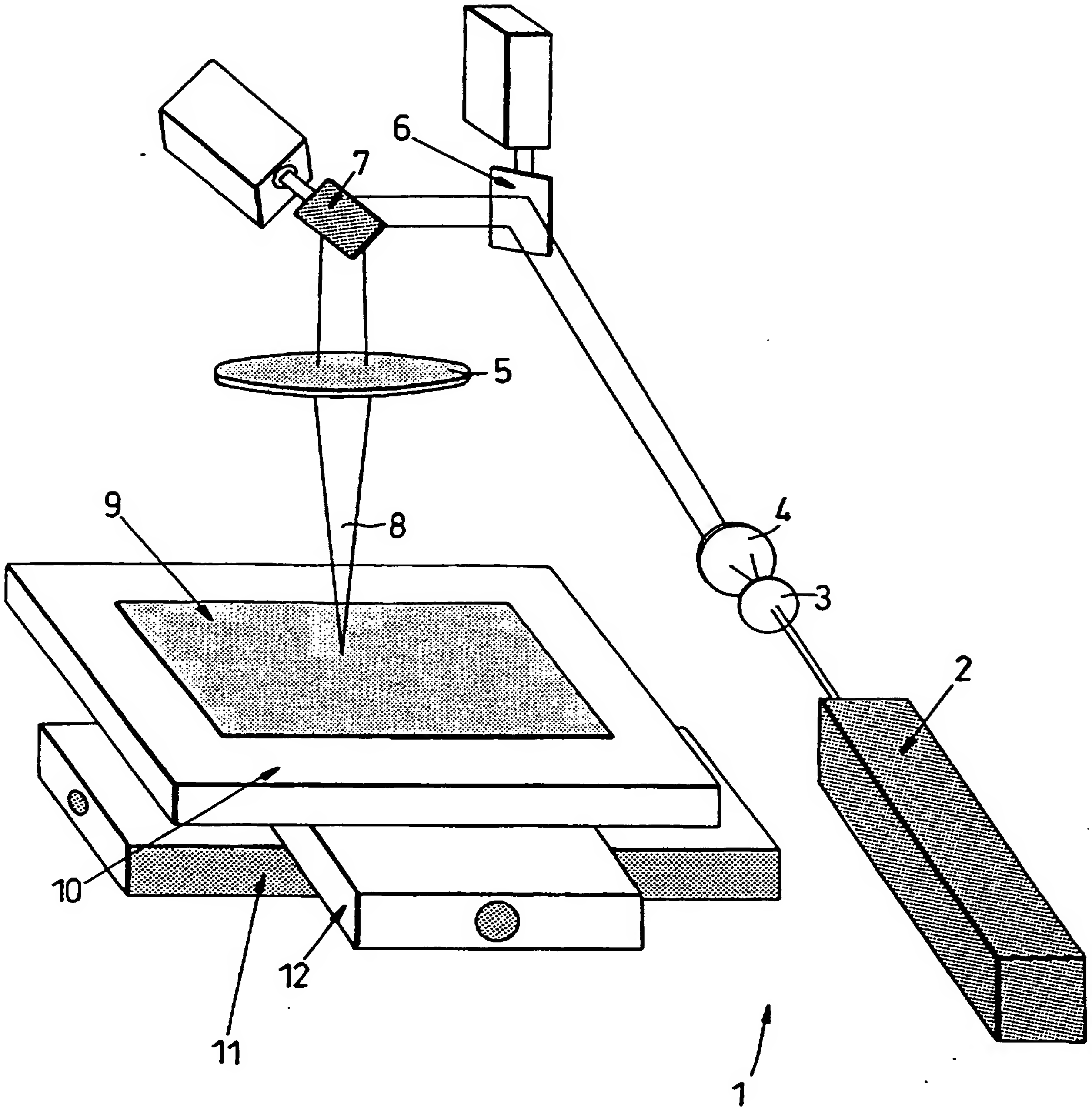

Fig. 1

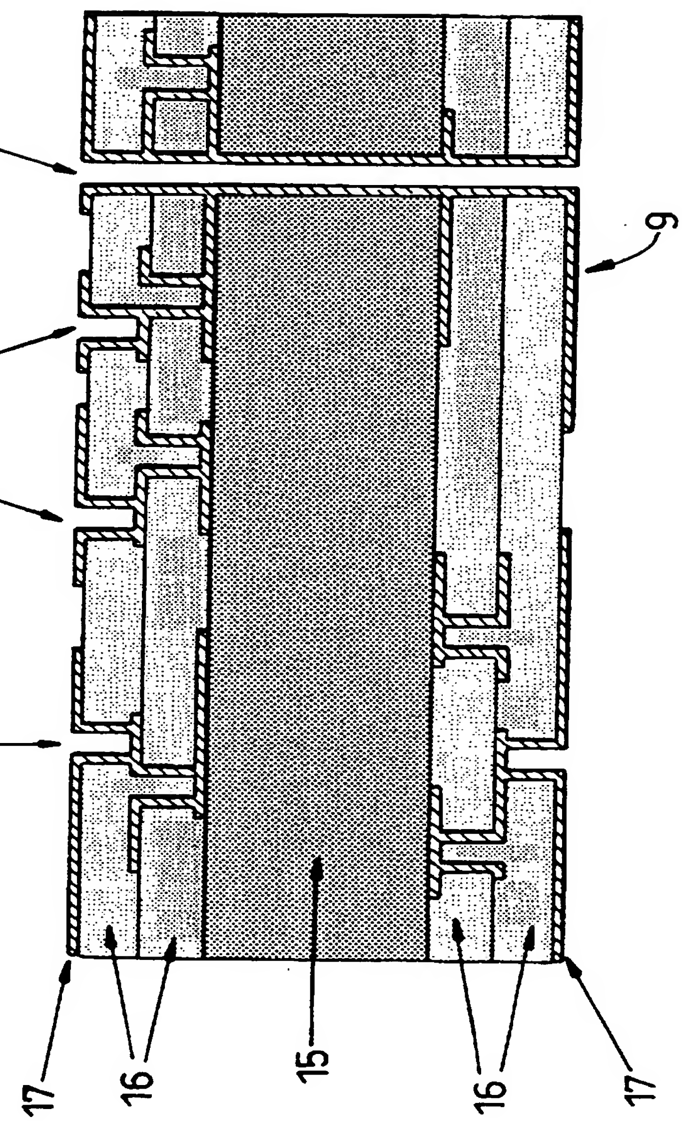

Fig. 2

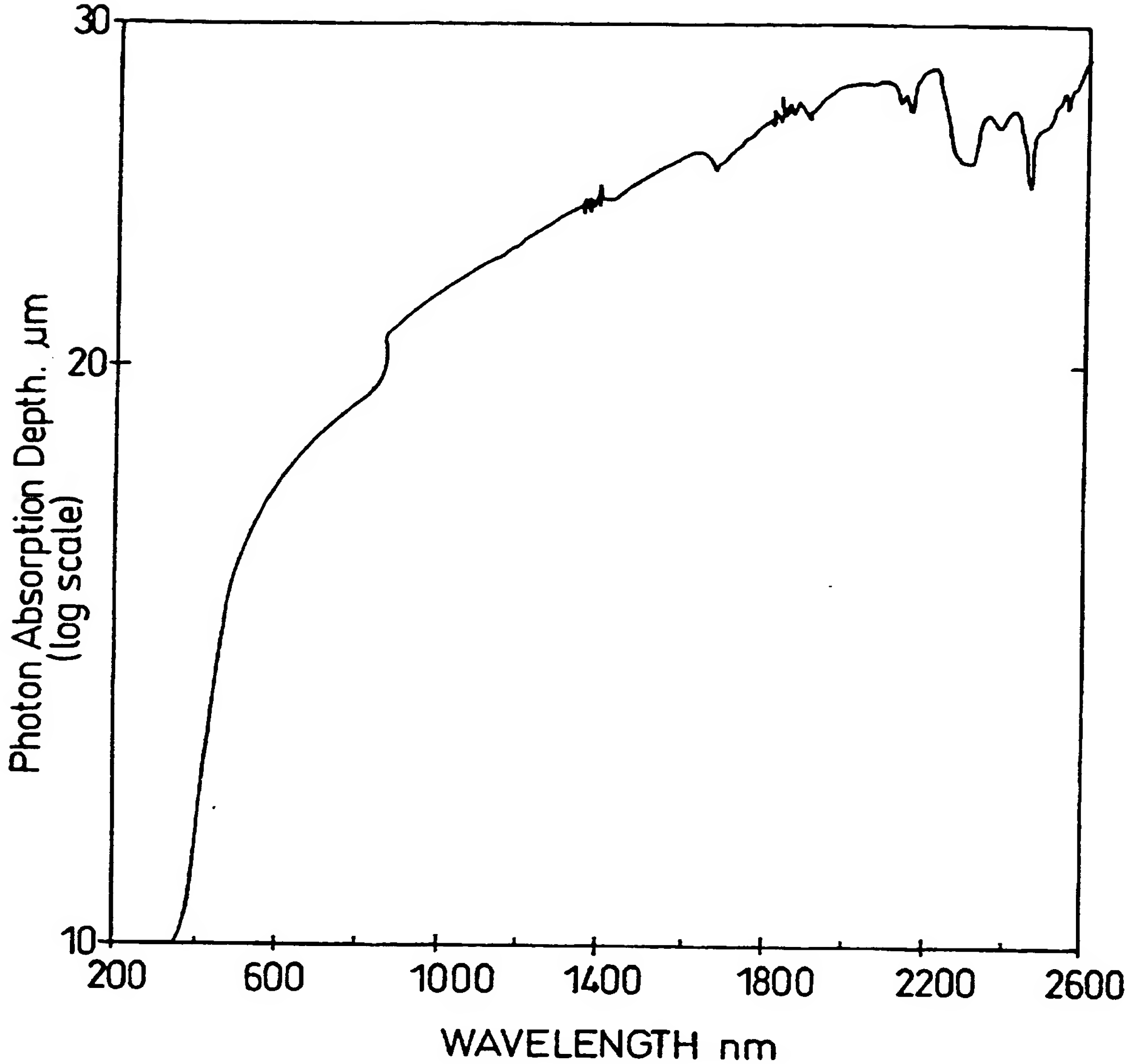
30
20
10
Photon Absorption Depth. µm
(log scale)
200
600
1000
1400
1800
2200
2600
WAVELENGTH nm

Fig. 3

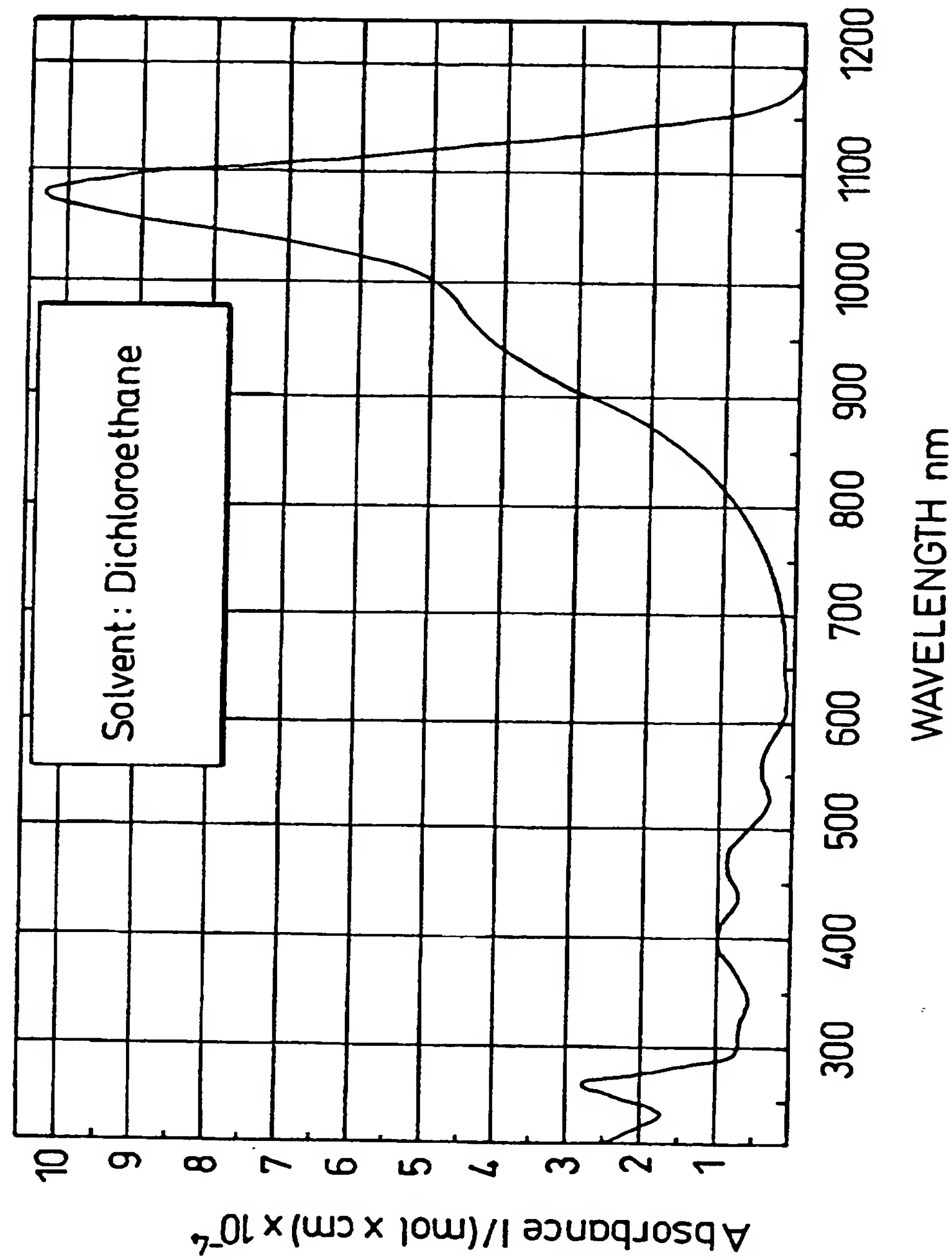
Solvent : Dichloroethane
Absorbance l/(mol x cm) x 10^-4
1 2 3 4 5 6 7 8 9 10
300 400 500 600 700 800 900 1000 1100 1200
WAVELENGTH nm

Fig. 4

LASER DRILLING OF HOLES IN MATERIALS

This invention relates to laser drilling of holes in materials, and particularly to the treating of materials to enhance the quality and ease of drilling therein.

For the purpose of this invention, the following definitions are used. Spectral wavelength regions are defined as: ultraviolet: 190 - 400nm, visible: 400 - 700nm, near infrared: 700nm - 1.5μm, mid infrared: 1.5 - 8μm, and far infrared: 8 - 100μm. The absorption depth (α^{-1}) of a material of a photon or photons is defined as the reciprocal of the absorption coefficient (α) of the material at the wavelength of the photon or photons.

There are a number of applications in which it is desirable to be able to laser drill holes in materials. For example, in electrical circuit interconnection packages, such as printed circuit boards (PCBs), printed wiring boards (PWBs), ball grid arrays (BGAs) or multichip modules (MCMs), it is generally necessary to provide interconnection or microvia holes, e.g. between dielectric layers of the package. Such holes are often laser drilled. For manufacturing applications like microvia laser drilling to be successful, minimising package processing costs is paramount. Hence lasers which have the lowest operating costs with the greatest reliability, drilling speed, productivity and hole quality are preferred for incorporating into microvia drilling tools. The lower operating costs etc. of infrared (particularly near and mid-infrared) compared to ultraviolet lasers make them better suited and preferable choices for incorporating into such tools. However, a significant proportion of electrical packages contain one or more electrically insulating dielectric materials. It has been found that holes cannot easily be drilled in these using at least near

or mid infrared lasers, as the holes produced have unacceptably poor quality often with collateral burning, charring, melting, cracking or delamination damage in surrounding regions. This is considered to be due to the low absorption of radiation from such lasers by the dielectric material. Although laser drilling can be achieved by increasing the exposure fluence to a level that boils and vaporises the material, the ensuing large temperature rise often leads to unacceptable collateral damage to peripheral regions of the holes.

Many multilayer packages exist which comprise dielectric and non-dielectric layers. These often require two different laser types for drilling, one type to drill holes in the dielectric layer(s) e.g. a far infrared laser, and the other type to drill holes in the non-dielectric layer(s) e.g. an ultraviolet laser, due to the different absorptions of laser radiation by the different materials. It is desirable to be able to drill such packages with only one laser type.

According to a first aspect of the present invention there is provided a method of laser drilling one or more holes in a material comprising treating the material to change its absorption depth at one or more wavelengths, and drilling one or more holes in the material using a laser emitting radiation at the wavelength or wavelengths.

The method may comprise treating the material such that its absorption depth at the wavelength or wavelengths is decreased. The method may comprise treating the material such that its absorption depth at the wavelength or wavelengths is in the range 0.01-10μm, more preferably in the range 0.1-1μm. By treating the material to change the absorption depth thereof, the efficacy of laser drilling holes therein may be increased. Preferably, treating the material will not adversely affect other

properties thereof, such as its dielectric behaviour, mechanical strength, flexibility, adhesive properties or thermal properties.

The method may comprise treating the material by adding one or more dopants thereto, or by irradiating the material e.g. with electromagnetic radiation, or by particle bombardment, or by heating the material e.g. using a laser radiation source, or by material layering, or by lamination treatment, or by a combination of any of these.

According to a second aspect of the present invention there is provided a method of laser drilling one or more holes in a material comprising treating the material such that the absorption depth thereof is changed at a wavelength or wavelengths by adding one or more dopants thereto, and drilling one or more holes in the material using a laser radiation source emitting radiation at the wavelength or wavelengths.

According to a third aspect of the present invention there is provided a method of laser drilling one or more holes in more than one material comprising treating one or more of the materials such that the absorption depth thereof is changed at a wavelength or wavelengths by adding one or more dopants thereto, and drilling one or more holes in the materials using a laser radiation source emitting radiation at the wavelength or wavelengths.

The methods of the second and third aspects of the invention may comprise treating the or each material such that its absorption depth at the wavelength or wavelengths is decreased. The methods may comprise treating the or each material such that its absorption depth at the wavelength or wavelengths is in the range 0.01-10μm, more preferably 0.1-1μm. The laser radiation at the wavelength or wavelengths will then

be strongly absorbed by the or each treated material, particularly at the surface thereof. Such absorption will create a rapid temperature and pressure rise which induces a miniexplosion at the surface of the material. A small crater is left behind as particulates or gaseous products are expelled away, which can be deepened by the continued application of laser radiation and a hole thus drilled with precision and control. With correct matching of the laser radiation wavelength(s), laser drilling can produce high quality holes with good wall edge definition and an almost complete lack of heat degradation and collateral damage to surrounding unexposed regions of the material and material below the drilling site. With suitable dopants chosen to decrease the absorption depth at appropriate wavelength(s), laser radiation sources having the lowest running costs and highest reliability etc. can be incorporated into tools used for drilling high quality holes.

The or each dopant may be an organic dopant. Additionally or alternatively, the or each dopant may be a molecular dopant. Additionally or alternatively, the or each dopant may be a dye molecule, for example $C_{42}H_{34}O_6Cl_2$, $C_{40}H_{30}S_2O_4Cl_2$ or $C_{50}H_{43}O_6Cl$, or an ink, particularly a coloured or black ink. Small or even trace concentrations of the or each dopant may be added to the or each material. For example, the percentage concentration of the or each dopant in the or each material may be a few percent or less, e.g. may be in the range 1-5%. The concentration of the or each dopant which is added to the or each material may depend on the absorption coefficient of the or each dopant.

When drilling holes with pulsed laser radiation, the threshold laser radiation fluence required for drilling holes in a material is approximately linearly proportional to the absorption depth of the material. Addition of the or each dopant to the or each material may also decrease the threshold

laser radiation fluence required to drill a hole, and may enhance the drilling efficiency.

The or each or some of the materials which are doped may be a dielectric material. The or each or some of the materials which are doped may be a polymer, dielectric material. The or each or some of the materials which are doped may be a resin, epoxy, phenolic, polyimide, or polytetrafluoethylene material, or an oxide ceramic material, nitride ceramic material or carbide ceramic material. The or each or some of the materials which are doped may contain embedded fibres such as aramid, glass, silica or carbon which provide added reinforcing strength. The or each or some of the materials which are not doped may be a non-dielectric material, e.g. a metal material, e.g. copper or aluminium or silver or gold, or a paste of e.g. tungsten or silver. The material or materials may form part of an electrical package, e.g. a PCB or a PWB or a BGA or a MCM. In the third aspect of the invention, the materials may comprise one or more dielectric materials, and one or more non-dielectric materials. These may form part of an electrical package. The dielectric and non-dielectric materials may have one or more holes drilled therein using a laser radiation source comprising a single laser. This simplifies the process of drilling packages comprising such materials, increases the drilling speeds and reduces the processing costs involved. The or each or some of the materials which are doped may form part of an ink jet printer, and the particularly the array of nozzles thereof. For example, the or each or some of the materials which are doped may be a non-wetting material, or a polyimide material, or a polymer material, particularly a fluorinated polymer material. Such materials may be used in the array of nozzles of an ink jet printer, where it is necessary to provide the material with one or more holes.

The methods may comprise laser drilling the or each or some of the holes using a punching mode. In this mode the focal spot size and shape of the radiation from the laser radiation source may determine the diameter of the hole being drilled. Alternatively, the methods may comprise laser drilling holes using a trepanning mode. In this mode the radiation from the laser radiation source, preferably concentrated in some way, may be moved in a circular, elliptical or spiral motion defining the hole diameter.

The methods may comprise using a laser radiation source comprising one or more lasers. The methods may comprise using a laser radiation source emitting radiation having a wavelength or wavelengths in the visible region. The methods may comprise using a laser radiation source emitting radiation having a wavelength or wavelengths in the infrared range. The methods may comprise using a laser radiation source comprising one or more neodymium (Nd) lasers, the Nd being provided in conjunction with a host. The host may be a crystalline host, and/or may be a glass host. The or each Nd laser may be a Nd:YAG laser which may emit radiation having a wavelength of 1.064μm, and/or a Nd:YLF laser which may emit radiation having a wavelength of 1.047μm, and/or a Nd:YVO_4 laser which may emit radiation having a wavelength of 1.064μm. The methods may comprise using a laser radiation source comprising one or more carbon dioxide (CO_2) lasers which may emit radiation having a wavelength in the range 9 - 11μm. The methods may comprise using a laser radiation source comprising one or more solid state titanium:sapphire lasers, or erbium, holmium or diode lasers. The methods may comprise using a laser radiation source comprising one or more gas excimer, copper vapour, HF, DF, carbon monoxide, or liquid dye lasers. The methods may comprise using a laser radiation source comprising one or more lasers and one or more optical elements which act to change the wavelength of the radiation produced by the or each laser.

The optical element or elements may be nonlinear, and may comprise a harmonic generator, a wavelength mixer, an optical parametric oscillator or an optical parametric amplifier, or a combination of any of these. The methods may comprise using a laser radiation source comprising a combination of any of the above lasers.

The methods may comprise using a pulsed laser radiation source. The duration of the radiation pulses may depend on the type of material or materials being drilled. The duration of the pulses may be in the range 1nsec - 1msec. Preferably, the pulse duration should be sufficiently short to minimize the heat affected zone (HAZ) in the material or materials. The size of the HAZ predicted theoretically is $2\sqrt{\varkappa\tau}$, where $\varkappa$ is the thermal diffusivity of the material and τ is the duration of each pulse. For thermally insulating dielectric materials, which have small values of $\varkappa$, τ may be less than 100μsec. The methods may comprise using a pulsed laser radiation source comprising one or more CO_2 lasers, which may be transversely-excited at atmospheric pressure (TEA) or rf-excited. The or each CO_2 laser may produce pulses of radiation of less than 1msec duration at repetition frequencies exceeding 100Hz. The methods may comprise using a pulsed laser radiation source comprising one or more Nd lasers, which may be pumped by flashlamps or by laser diodes, or may be Q-switched. The or each Nd laser may produce pulses of radiation of less than 200nsec duration at repetition frequencies exceeding 1kHz.

The or each hole may have a diameter in the range 1-1000μm, more preferably 10-100μm. The methods preferably comprise drilling holes at a rate or rates of 100 holes/sec or more. The methods may comprise laser drilling microvia holes in the material or materials of, for example, an electrical package. The microvia holes may be blind and/or through microvia holes.

According to a fourth aspect of the present invention there is provided a laser drilling apparatus for carrying out the method of the first and second and third aspects of the invention.

The laser drilling apparatus may be able to carry out the method of the first aspect of the invention or the method of the second aspect of the invention or the method of the third aspect of the invention or any combination of the methods. The laser drilling apparatus may comprise a laser radiation source comprising one or more lasers. The laser drilling apparatus may comprise a laser radiation source emitting radiation having a wavelength or wavelengths in the visible region. The laser drilling apparatus may comprise a laser radiation source emitting radiation having a wavelength or wavelengths in the infrared range. The laser radiation source may comprise one or more Nd lasers, the Nd being provided in conjunction with a host. The host may be a crystalline host, and/or may be a glass host. The or each Nd laser may be a Nd:YAG laser which may emit radiation having a wavelength of 1.064μm, and/or a Nd:YLF laser which may emit radiation having a wavelength of 1.047μm, and/or a Nd:YVO_4 laser which may emit radiation having a wavelength of 1.064μm. The laser radiation source may comprise one or more CO_2 lasers which may emit radiation having a wavelength in the range 9 - 11μm. The laser radiation source may comprise one or more solid state titanium:sapphire lasers, or erbium, holmium or diode lasers. The laser radiation source may comprise one or more gas excimer, copper vapour, HF, DF, carbon monoxide, or liquid dye lasers. The laser radiation source may comprise one or more lasers and one or more optical elements which act to change the wavelength of the radiation produced by the or each laser. The optical element or elements may be nonlinear, and may comprise a harmonic generator, a wavelength mixer, an optical parametric

oscillator or an optical parametric amplifier, or a combination of any of these. The laser radiation source may comprise a combination of any of the above lasers.

The laser drilling apparatus may comprise a pulsed laser radiation source. The duration of the radiation pulses may depend on the type of material or materials being drilled. The duration of the pulses may be in the range 1nsec - 1msec. Preferably, the pulse duration should be sufficiently short to minimize the heat affected zone (HAZ) in the material or materials. The size of the HAZ predicted theoretically is $2\sqrt{\varkappa\tau}$, where $\varkappa$ is the thermal diffusivity of the material and τ is the duration of each pulse. For thermally insulating dielectric materials, which have small values of $\varkappa$, τ may be less than 100μsec. The pulsed laser radiation source may comprise one or more CO_2 lasers, which may be transversely-excited at atmospheric pressure (TEA) or rf-excited to produce pulses of radiation. The or each CO_2 laser may produce pulses of radiation of less than 1msec duration at repetition frequencies exceeding 100Hz. The laser radiation source may comprise one or more Nd lasers, which may be pumped by flashlamps or by laser diodes, or may be Q-switched. The or each Nd laser may produce pulses of radiation of less than 200nsec duration at repetition frequencies exceeding 1kHz.

The laser drilling apparatus may comprise one or more optical components, such as computer-controlled, moving-magnet, galvanometer scanning mirrors. The or each or some of the optical components may act to shape the radiation from the laser radiation source. Additionally or alternatively, the or each or some of the optical components may act to image an object e.g. an aperture placed in the radiation from the laser radiation source. Additionally or alternatively, the or each or some of the optical components may act to concentrate e.g. focus the radiation from

the laser radiation source. Additionally or alternatively, the or each or some of the optical components may act to position the radiation from the laser radiation source on the surface of the or each material. Positioning is preferably carried out with high speed and accuracy. The or each or some of the optical components may act to position the radiation from the laser radiation source onto different locations on the surface of the or each material. Additionally or alternatively, the or each material may be moved underneath the radiation from the laser radiation source. The or each material may be moved using a motorised table or tables. The laser drilling apparatus preferably drills holes in the diameter range 1-1000μm, more preferably 10-100μm. The laser drilling apparatus preferably drills holes at a rate or rates of 100 holes/sec or more. The laser drilling apparatus preferably drills holes at a cost in the region of or less than 1 cent per 1000 holes.

According to a fifth aspect of the present invention there is provided a doped material having one or more dopants therein which change the absorption depth of the doped material at a wavelength or wavelengths.

The absorption depth of the doped material may be in the range 0.01-10μm, more preferably 0.1-1μm. The or each or some of the dopants may be an organic dopant. Additionally or alternatively, the or each or some of the dopants may be a molecular dopant. Additionally or alternatively the or each or some of dopants may be a dye molecule, for example $C_{42} H_{34} O_6 Cl_2$, $C_{40} H_{30} S_2 O_4 Cl_2$ or $C_{50} H_{43} O_6 Cl$, or an ink, particularly a coloured or black ink. Small or even trace concentrations of the or each dopant may be added to the or each material. For example, the percentage concentration of the or each dopant in the or each material may be a few percent or less, e.g. may be in the range 1-5%. The doped material may comprise a dielectric material. The doped material may

comprise a polymer dielectric material. The doped material may be a resin, epoxy, phenolic, polyimide, or polytetrafluoethylene material, or an oxide ceramic material, a nitride ceramic material or a carbide ceramic material. The doped material may contain embedded fibres such as aramid, glass, silica or carbon which provide added reinforcing strength. The doped material may form part of an electrical package, e.g. a PCB or a PWB or a BGA or a MCM. The doped material may form part of an ink jet printer, particularly the nozzle thereof.

An embodiment of the invention will now be described by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic representation of a laser drilling apparatus according to the fourth aspect of the invention;

Figure 2 illustrates a four-layer printed circuit board;

Figure 3 shows the variation of absorption depth versus wavelength from the ultraviolet to mid-infrared spectral regions of an undoped resin material used in the construction of the dielectric layer in PCBs and PWBs, and

Figure 4 shows the absorbance versus wavelength in the ultraviolet and near-infrared spectral regions of the dye molecule C_{40} H_{30} S_2 O_4 Cl_2.

Figure 1 shows a laser drilling apparatus 1 comprising a pulsed laser radiation source comprising a Nd:YAG laser 2, emitting radiation at a wavelength of 1.064µm, with an average power in the range 10-30W. The Nd:YAG laser is pumped by laser diodes, and is Q-switched to

produce pulses of radiation each with a duration in the range 20-100nsec, at repetition frequencies in the range 1-100kHz. The apparatus further comprises beam shaping components 3,4,5 and computer-controlled, moving-magnet, galvanometer scanning mirrors 6,7 used to position a focused beam 8 of laser radiation from the Nd:YAG laser onto the surface of the doped material 9 being drilled placed on an optical platform 10. The apparatus also comprises motorised tables 11,12 so that the material can be moved underneath the beam 8.

The doped material 9 comprises part of a four-layer printed circuit board (Figure 2). The board comprises a substrate core 15, electrically insulating dielectric layers 16 and conducting layers 17 of copper metal. Blind 18 and through 19 microvia holes are drilled in the board using the beam of radiation 8, which, after metal plating through the hole, provide electrical interconnections between the layers. The dielectric layers 16 are 70μm thick, and are composed of the doped material 9 which is a resin-based material. The absorption depth versus wavelength spectrum of the undoped resin-based material is shown in Figure 3. As can be seen, in the spectral region 400-2600nm, the undoped material is relatively transmissive having an absorption depth greater than 10μm. In particular, at the 1.064μm wavelength of the Nd:YAG laser the absorption depth of the material is approximately 22μm. Using this laser to drill holes in this material will give unsatisfactory hole quality.

Figure 4 shows the absorbance spectrum of the dye molecule $C_{40} H_{30} S_2 O_4 Cl_2$ when dissolved in dichloroethane solvent. This molecule may be used as a dopant in a dielectric material, and possibly the resin-based dielectric material 9. For this molecule it can be seen that the peak of its absorption in the visible and near infrared spectral regions occurs at 1μm wavelength, close to the wavelengths of the various Nd lasers. Since the

absorbance at this wavelength is approximately 10^5l/mole/cm corresponding to a molecular absorption cross-section of approximately $4x10^6cm^2$, a dopant concentration of only a few percent or less added to a dielectric material enables high quality blind and through microvia holes to be drilled in a board containing a dielectric material doped with this molecule using a Nd laser radiation source. This laser radiation source can also drill blind and through microvia holes in the metal layers of the board.

CLAIMS

1. A method of laser drilling one or more holes in a material comprising treating the material to change its absorption depth at one or more wavelengths, and drilling one or more holes in the material using a laser emitting radiation at the wavelength or wavelengths.

2. A method according to claim 1 which comprises treating the material such that its absorption depth at the wavelength or wavelengths is in the range 0.01-10μm.

3. A method of laser drilling one or more holes in a material comprising treating the material such that the absorption depth thereof is changed at a wavelength or wavelengths by adding one or more dopants thereto, and drilling one or more holes in the material using a laser radiation source emitting radiation at the wavelength or wavelengths.

4. A method of laser drilling one or more holes in more than one material comprising treating one or more of the materials such that the absorption depth thereof is changed at a wavelength or wavelengths by adding one or more dopants thereto, and drilling one or more holes in the materials using a laser radiation source emitting radiation at the wavelength or wavelengths.

5. A method according to claim 3 or claim 4 which comprises treating the or each material such that its absorption depth at the wavelength or wavelengths is decreased.

6. A method according to any of claims 3 to 5 which comprises treating the or each material such that its absorption depth at the wavelength or wavelengths is in the range 0.01-10μm.

7. A method according to claim 6 which comprises treating the or each material such that its absorption depth at the wavelength or wavelengths is in the range 0.1-1μm.

8. A method according to any of claims 3 to 7 in which the or each dopant is an organic dopant.

9. A method according to any of claims 3 to 8 in which the or each dopant is a molecular dopant.

10. A method according to any of claims 3 to 9 in which the or each dopant is a dye molecule

11. A method according to claim 10 in which the dye molecule is $C_{42} H_{34} O_6 Cl_2$.

12. A method according to claim 10 in which the dye molecule is $C_{40} H_{30} S_2 O_4 Cl_2$.

13. A method according to claim 10 in which the dye molecule is $C_{50} H_{43} O_6 Cl$.

14. A method according to claim 10 in which the dye molecule is an ink.

15. A method according to any of claims 3 to 14 in which the percentage concentration of the or each dopant in the or each material is in the range 1-5%.

16. A method according to any of claims 3 to 15 in which the or each or some of the materials which are doped is a dielectric material.

17. A method according to claim 16 in which the or each or some of the materials which are doped is a polymer dielectric material.

18. A method according to claim 16 or claim 17 in which the or each or some of the materials which are doped is chosen from the group of resins, epoxies, phenolics, polyimides, polytetrafluoethylenes, oxide ceramic materials, nitride ceramic materials or carbide ceramic materials.

19. A method according to any of claims 4 to 18 in which the or each or some of the materials which are not doped is a non-dielectric material.

20. A method according to claim 19 in which the non-dielectric material is a metal material.

21. A method according to claim 19 in which the non-dielectric material is a paste.

22. A method according to any of claims 3 to 21 in which the material or materials form part of an electrical package.

23. A method according to any of claims 3 to 21 in which the material or materials form part of a nozzle array of an ink jet printer.

24. A method according to any of claims 3 to 23 which comprises laser drilling the or each or some of the holes using a punching mode.

25. A method according to any of claims 3 to 23 which comprises laser drilling holes using a trepanning mode.

26. A method according to any of claims 3 to 25 which comprises using a laser radiation source comprising one or more lasers.

27. A method according to any of claims 3 to 26 which comprises using a laser radiation source emitting radiation having a wavelength or wavelengths in the visible range.

28. A method according to any of claims 3 to 26 which comprises using a laser radiation source emitting radiation having a wavelength or wavelengths in the infrared region.

29. A method according to claim 28 which comprises using one or more Nd lasers, the Nd being provided in conjunction with a host.

30. A method according to claim 29 which comprises using one or more Nd:YAG lasers which emit radiation having a wavelength of 1.064μm.

31. A method according to claim 28 which comprises using one or more carbon dioxide lasers.

32. A method according to claim 31 which comprises using one or more carbon dioxide lasers which emit radiation having a wavelength in the range 9-11 μm.

33. A method according to any of claims 3 to 32 which comprises using a pulsed laser radiation source.

34. A method according to claim 33 in which the duration of the pulses is in the range 1nsec-1msec.

35. A method according to claim 33 or claim 34 in which the pulsed laser radiation source comprises one or more CO_2 lasers.

36. A method according to claim 35 in which the or each CO_2 laser produces pulses of radiation of less than 1msec duration at repetition frequencies exceeding 100Hz.

37. A method according to claim 33 or 34 in which the pulsed laser radiation source comprises one or more Nd lasers.

38. A method according to claim 37 in which the or each Nd laser produces pulses of radiation of less than 200nsec duration at repetition frequencies exceeding 1kHz.

39. A method according to any of claims 3 to 38 in which the or each hole has a diameter in the range 1-1000μm.

40. A method according to claim 39 in which the or each hole has a diameter in the range 10-100μm.

41. A method according to any of claims 3 to 40 which comprises drilling holes at rates in excess of 100 holes/sec.

42. A method according to any of claims 3 to 41 which comprises laser drilling microvia holes in the material or materials.

43. A laser drilling apparatus for carrying out the method according to any of claims 1 to 42.

44. A laser drilling apparatus according to claim 43 which comprises one or more Nd lasers, the Nd being provided in conjunction with a host.

45. A laser drilling apparatus according to claim 44 which comprises one or more Nd:YAG lasers which emit radiation having a wavelength of 1.064μm.

46. A laser drilling apparatus according to claim 43 which comprises one or more carbon dioxide lasers.

47. A laser drilling apparatus according to any of claims 43 to 46 which comprises one or more optical components.

48. A laser drilling apparatus according to claim 47 in which the optical component or components comprise computer-controlled, moving-magnet, galvanometer scanning mirrors.

49. A laser drilling apparatus according to any of claims 43 to 48 which comprises a motorised table or tables for moving the or each material underneath the radiation from the laser radiation source.

50. A laser drilling apparatus according to any of claims 43 to 49 which drills holes in the diameter range 1-1000μm.

51. A laser drilling apparatus according to claim 50 which drills holes in the diameter range 10-100μm.

52. A laser drilling apparatus according to any of claims 43 to 51 which drills holes at a rate or rates of 100 holes/sec or more.

53. A doped material having one or more dopants therein which change the absorption depth of the doped material at a wavelength or wavelengths.

54. A doped material according to claim 53 which has an absorption depth in the range 0.01-10μm.

55. A doped material according to claim 54 which has an absorption depth in the range 0.1-1μm.

56. A doped material according to any of claims 53 to 55 in which the or each or some of the dopants is an organic dopant.

57. A doped material according to any of claims 53 to 56 in which the or each or some of the dopants is a molecular dopant.

58. A doped material according to any of claims 53 to 57 in which the or each or some of the dopants is a dye molecule.

59. A doped material according to any of claims 53 to 58 in which the percentage concentration of the or each or some of the dopants in the or each material is in the range of 1-5%.

60. A doped material according to any of claims 53 to 59 in which the doped material comprises a dielectric material.

61. A doped material according to claim 60 in which the dielectric material is a polymer dielectric material.

62. Methods of laser drilling one or more holes in one or more materials substantially as described herein with reference to the accompanying drawings.

63. A laser drilling apparatus substantially as described herein with reference to Figure 1 of the accompanying drawings.

64. A doped material substantially as described herein with reference to the accompanying drawings.

Application No: GB 9913617.8
Claims searched: 1-42 and 62

Examiner: A.R.Martin
Date of search: 20 July 1999

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): B3V

Int Cl (Ed.6): B23K 26/00

Other: On line databases WPI,EPODOC,JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	WO 98/08645 A	British Polythene see claim 1	Claim 1,3 and 4 at least
X	EP 0090565 A	Fujitsu see claim 1	"
X	EP 0796695 A	British Aerospace see claim 1	"
X	EP 0278643 A	Duley see claim 2	"
X	US 4964212 A	Commissaret Atomique see claim 1	"
X	US 5169678 A	GEC see claim 1	"
X	Y.Kawamura,K.Toyoda,S.Namba Applied Physics Letters,40,374(1982)		"
X	T.J.Chang,H.Hiraoka,A.Modl Applied Physics,A45,277(1988)		"

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.